ENVIRONMENTAL ASSESSMENT OF MĀKUA MILITARY RESERVATION IN HAWAII

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ABSTRACT

The Army has conducted several site-specific environmental studies to address the major public concerns at Mākua Military Reservation (MMR). The monitoring and numerical technologies used at MMR may be of interest for other sites with the similar problems. Past sampling has shown that none of the samples had detectable concentrations of energetics or semi-volatile organic compounds. The nitrate and nitrite concentrations in the samples were below risk-based health criteria and drinking water standards. Detectable levels of barium, chromium, lead, mercury, and nickel were also below risk-based health criteria and drinking water standards. The study concluded that the basal aquifer at MMR was not contaminated.

1. INTRODUCTION

Mākua Military Reservation (MMR) in Hawaii has been used for six decades to train US troops. The past and current use of MMR for military training has deposited several chemical compounds throughout MMR. Possible compounds released by these munitions include metals, explosives, and byproducts of explosives. Chemical compounds from these munitions may have entered the environment through a number of processes, such as emission of particles and gases into the air, percolation into the groundwater, runoff into surface water, runoff and erosion of contaminated solid particles into surface water, and transport to nearby muliwai by streams flowing from MMR.

One site known to be a likely source of chemical contamination is the open burn/open detonation (OB/OD) area (Figure 1), a RCRA treatment facility that is undergoing delayed closure by the EPA. The area is approximately four acres and lies down slope of the access road. Army, Air Force, Navy, and Marine Corps personnel used this area to burn and detonate a variety of materials from the 1960s into the 1990s.

The Army has been conducting several site-specific field geological, environmental and cultural resource studies at MMR to address the major public concerns.[1]

This paper provides an overview of the geologic and environmental field investigations. Sampling protocols described here reflect many of the public comments and concerns attained during the public meetings.

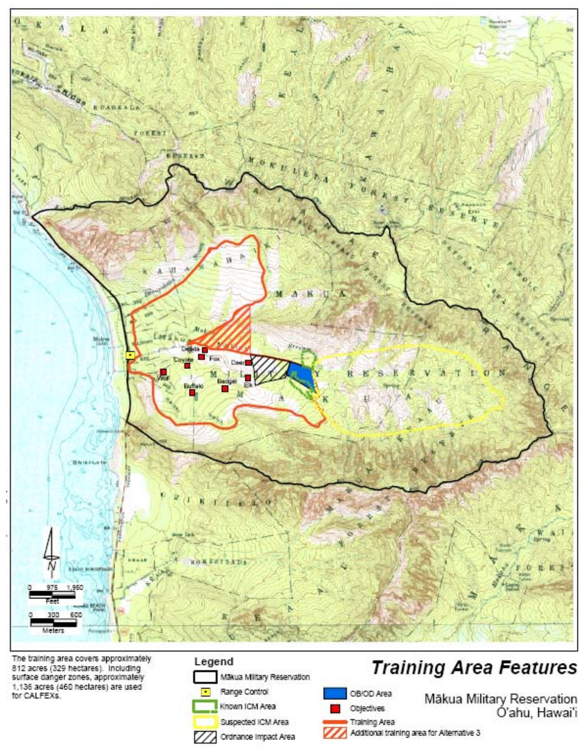

Figure 1. Training area features and the open burn/open detonation (OB/OD) area at MMR

2. REGIONAL GEOLOGY

Makua Valley is located within the eroded remnant of the Waianae Volcano, which was active between 2.9 and 3.9 million years ago (Presley et.al. 1997). The

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overall stratigraphy of the volcano consists of two volcanic formations that include the shield building Waianae Volcanics and the post-shield building Kolekole Volcanics (Langenheim and Clague, 1987). The Waianae Volcano had a well-developed caldera centered near Laulaulie and Waianae Valleys. The depth of erosion of in these valleys has been greatly impacted by Pleistocene sea level changes. During the period of greatest glacial melting, (approximately 2-3 thousand years ago) the sea level was about 9 feet above present sea level. During the time of glacial maximum (approximately 18,000 years ago) the sea level was more than 350 feet below present sea level.

2.1. Region of influence for geology

At MMR, the fate and transport of chemical contaminants has been identified as an issue of concern; therefore, the discussion of geologic resources has been broadened to include the distribution and fate and transport of chemical contaminants in soils, sediments, and other geologic materials.

The region of influence for geology and soils includes the Mākua Valley, the adjacent attached valleys in which live-fire training and associated activities will occur, the adjacent beach, and the near shore area. Laws or regulations that govern geologic resources at MMR include EPA Region IX PRGs, the State Coastal Zone Management Program, and the Farmland Protection Act. Contaminant concentrations in soils are compared to EPA Region IX industrial PRGs for soils. The purpose of comparing observed chemical concentrations in soils to the PRGs is to determine whether further assessment of health risks associated with on-site concentrations is needed. PRGs are not promulgated cleanup standards, and higher or lower standards may be reasonably applied to sites based on site specific exposure levels rather than the default exposure assumptions used to develop the PRGs.

In addition, it is usually not appropriate to rely on individual sample results for comparison to the PRGs; a better approach is to use a set of sample results collected over an area of exposure, or over a period of time, to evaluate the average concentrations to which people may be exposed. This increases the degree of confidence in the results and tends to better represent the actual exposures. The EPA recommends using a statistical sample and comparing the calculated 95 percent upper confidence limit (UCL) of the sample set to the PRGs. The UCL is a conservative estimate of the average concentration in a set of samples. Therefore, this comparison usually yields a conservatively protective estimate of the health risk associated with the chemical. This method was used to evaluate surface soil results for metals and selected contaminants where multiple detections were observed. Some risks from individual contaminants are additive with the risks from other contaminants. An accurate determination of cumulative risks can be complex because, for example, not all chemicals affect the same organs, and some chemicals when combined may have a greater effect than they would have individually. A screening level analysis is used to determine whether further assessment of risk is needed. If the risk from exposure to the principal chemicals of concern, based on comparison to PRGs, is within the acceptable risk range, and if the types of exposures that would occur at the site are similar to those assumed in the PRGs, then generally no further action is needed to address the chemicals at the site. Geological issues identified included sediment transport; soil contamination and its effects on groundwater and crops; frequency of soil sampling; soil erosion and land maintenance; and landslides.

2.2. Soil characteristics

A complex mixture of soils occurs in Mākua Valley as a result of the many microenvironments and variations in slope (Figure 2). The side slopes of Mākua Valley are too steep to hold more than a thin covering of soil and are generally classified as Rocky or Stony Land. The south-facing slope of the Kahanahāiki Valley, east of Punapōhaku Stream, also is classified as Stony Land, although a small enclave of Helemano silty clay occurs on colluvial deposits in the upper eastern part of this valley.

Helemano soils are well-drained silty clays that occur in V-shaped gulches. The erosion hazard is severe to very severe. Most of the channel of Mākua Stream and some of the lower reach of Kaiahi Gulch is underlain by Pulehu very stony clay loam. The soil is developed on alluvial fans and stream terraces. Permeability is slow, and the erosion hazard is slight. The soil is generally about 5 feet (2 meters) thick and underlain by coarse gravelly or sandy alluvium. This soil type is used for sugarcane, truck crops such as ginger and taro, and pasture, but as 3 percent of the surface area is covered by stones, the soil is difficult to work. Pulehu clay soils, with fewer stones, also are found along the lowlying lands inland from Farrington Highway. Some of these soils are developed on land that is subject to flooding. The upper portion of the main lobe of alluvial deposits in Mākua Valley, which includes the OB/OD area and most of the area in which live-fire training exercises occur, is underlain by Lolekaa silty clay soils. Lolekaa soils vary somewhat depending on the slope and elevation at which they occur. They consist of well-drained soils developed in old gravelly colluvium and alluvium on fans and terraces. According to the Natural Resources Conservation Service (NRCS), annual rainfall in areas with these soils is 70 to 90 inches (178 to 229 centimeters), and these soils occur at elevations from sea level to 500 feet (152 meters). However, mean annual rainfall in the portion of Mākua Valley where these soils

occur may be in the range of 40 to 60 inches (102 to 229 centimeters), and the elevation ranges from about 400 to over 1,000 feet (122 to 305 meters). Access to the area in which these soils are mapped has been closed for some time due to military activities and the possible presence of UXO.

Most of the shoreline trail traverses land that is classified as Rock Outcrop, Rock Land, or Stony Steep Land. The following soils are adjacent to or interspersed with the rocky land on the north shore:

- Stony soils (Waialua stony silty clay, Lualualei extremely stony clay, and a quarry);
- Sandy soils (Jaucas sand near the west end of DMR and beach sand); and
- Small patches of other soils (Mokuleia clay loam near DMR and Lualualei clay near Kaena Point).

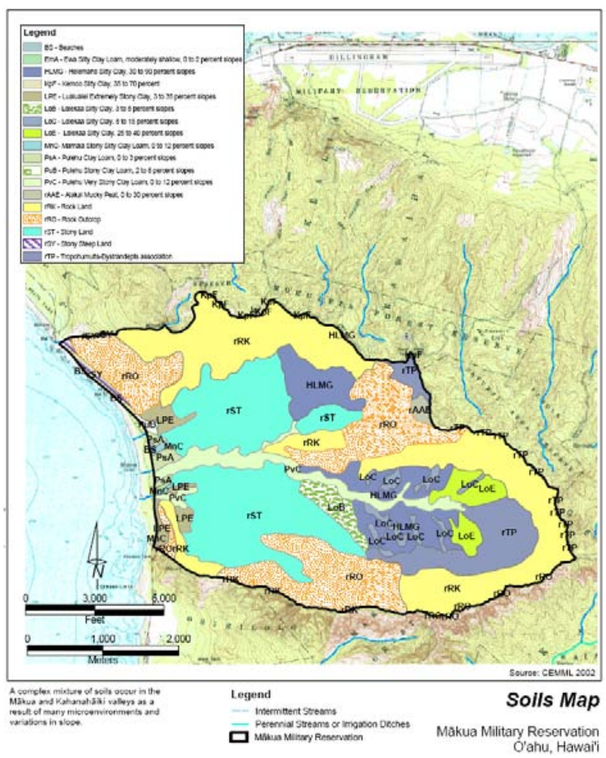

Figure 2. Soil map of MMR

3.0 CHEMICALS OF CONCERN USED IN TRAINING

Energetic materials, such as nitroglycerine, tetryl, RDX, HMX, TNT, and 2,4-DNT have been found at hazardous waste sites that contain buried ammunition wastes and have been known to affect the soil, surface water, groundwater, and air. Exposure to high levels may affect the nervous system and the blood (USDOHHS 1999). Because energetics are used in training on MMR, they are being analyzed as part of the ongoing air and hydrogeologic field investigations. The hydrogeologic investigation showed concentrations of energetics in soils at the following locations:

- OB/OD area;
- Within berms at Objective Deer;
- Weather station burn pan area;
- In streambed sediments of Mākua Stream;
- Demo pit; and
- Objectives Wolf, Deeds, and Badger.

None of the findings showed concentrations of energetics above EPA Region IX PRG levels.

Due to various studies documenting the use and disposal of Agent Orange and depleted uranium on military bases within the US, public concern prompted research to confirm that these materials were not stored, used, or disposed of in Hawaii. Various Air Force studies document that in 1971, chemical agents stored in Okinawa were transported to Johnston Island and stored at the Chemical Storage Facility there. Public Law 91-672, passed in 1972, prohibited the transport of chemical agents from Okinawa to any of the 50 states and authorized destruction of Agent Orange outside these areas. In 1972, the 1.4 million-gallon (5.3 million-liter) stockpile of Agent Orange amassed during the Vietnam War was transported directly to Johnston Island and placed in storage there. In 1977, Agent Orange stored at Johnston Island, as well as in Mississippi, prior to Public Law 91-672, was destroyed by high-temperature incineration at sea in the South Pacific (USARHAW and 25th ID(L) 2001a). There is no record of Agent Orange being used, stored, or disposed of on Oahu.

Military installations hosting training with depleted uranium rounds must apply for and be granted a license from the Nuclear Regulatory Commission for possession of depleted uranium cartridge penetrators. Currently, none of the three installations in the United States that have such licenses are in Hawaii. A memorandum by the Deputy Chief of Staff, Logistics, Munitions states that a records search for depleted uranium rounds determined that these types of munitions were never a part of the Army's inventory in Hawaii and that the Army did not and does not have any plans to introduce depleted uranium to the state.

3.1 Metals

In addition to explosives residues, metals contained in various munitions may also be deposited on the ranges as a result of live-fire training activities and past disposal practices. Among the metals present in some explosives are lead and mercury. Lead is also used in the projectiles of small arms ammunition.

Comparison of the metals concentrations to background concentrations in soils from the island of Hawaii shows that the 95 percent UCL for most of the metals in samples from MMR are within the background range (Halbig et al. 1985). The exceptions are arsenic, lead, and selenium. Only arsenic exceeds the industrial soil PRG based on a carcinogenic endpoint. Arsenic is used in rodenticides and wood preservatives and is a common contaminant in developed areas of Oahu. Based on these observations, it appears that although some of the arsenic found in the soil samples may not be from mineral sources, the arsenic is widely distributed, perhaps as a result of past use of pesticide. If it derived from military activities, there would likely be localized occurrences of higher than average concentrations in areas where military activities are focused, and this does not appear to be the case.

3.2 Lead from ammunition

Lead is used in the manufacturing of ordnance/ammunition, such as those munitions used for small arms training. Lead is used in the projectiles of small arms ammunition. Bullets are typically made up of an alloy of lead and antimony, which makes the bullet harder. Lead accumulating over the long term in backstops, range floors, and berms can leach into groundwater, be transported off-site by stormwater, be ingested by wildlife, or become airborne. Erosion can overload streams and rivers with sediments. The type and amount of ammunition used on the range along with its operational history greatly influences the risk of lead migration to groundwater. Different calibers of ammunition contain varying amounts of lead; therefore, when looking at the risk of lead migration, both the total number and type of rounds fired must be taken into consideration.

Preliminary results of the current hydrogeologic investigation show concentrations of lead above industrial PRG levels in soil samples taken at Objective. Based on the limited detection of lead on the range and the isolated areas where it was found, lead is less of a contaminant than expected. As lead does not appear to be a migrating contaminant, no mitigation or maintenance is necessary until the range is closed.

3.3 Pesticides

Hydrogeologic sampling being conducted by the Army includes testing for pesticides that may have been released to the environment through spills or disposal. Preliminary results of the hydrogeologic studies found multiple areas within MMR that contain concentrations of pesticides below PRG levels. Heptachlor epoxide, a pesticide, was detected in a monitoring well (MW-3C) in the second round of sampling (but not in the first round) at a concentration of 0.039 μg/L, which is above the PRG of 0.007 μg/L but less than the MCL of 0.20 μg/L.

3.4 Polychlorinated Biphenyls

No PCB-containing equipment or materials are located on MMR (Husemann 2003d). Soil samples collected as part of the 1994 Halliburton NUS study contained PCBs in the soil above background concentrations. These contaminants were found in soils at the OB/OD area. The source of these chemicals is unknown; however, historic disposal of materials other than munitions in the OB/OD area was not uncommon. The concern was that these contaminants could be transported off-site by wind, surface water, or groundwater, as contaminants were found at depths ranging from between 6 inches (15 centimeters) below ground surface (bgs) to 12 feet (4 meters) bgs.

Because of the Halliburton NUS study results, hydrogeologic investigations included testing water and soil for a large number of different chemicals and PCB. Results of the hydrogeologic investigation showed PCBs in two soil samples at the MMR OB/OD area. Concentrations were lower than industrial PRGs. PCBs were not detected in any other areas of MMR.

3.5 Dioxins

Dioxins were detected in a large number of surface soil samples at MMR and could be a potential group of chemicals of concern. As with the results from the groundwater samples, the reported concentrations of the various isomers of dioxins were converted to their respective equivalent toxicity values relative to the 2,3,7,8-TCDD isomer, for comparison to the EPA Region IX industrial soil PRG. For the 102 surface/near-surface soil samples, the mean TCDD equivalent concentration was 0.00266 μg/kg with a 95 percent UCL of 0.00743 μg/kg. Using this potential exposure level, the carcinogenic occupational risk value is 4.64×10^{-7}, which is considered an acceptable risk level for occupational part-time exposure to these soils. Furthermore, similar concentrations of dioxins were detected in soil samples from background locations outside the boundaries of MMR. Dioxins are known to be widely distributed in the environment from atmospheric deposition from a variety of sources (for example, burning of plastics), and the detected concentrations do not indicate a significant onsite source of the dioxin.

3.6 Petroleum, oils, and lubricants

The analytical results of the 1994 Halliburton NUS soil sampling showed that none of the soils used for past training exceeded the EPA's conservative public health

criteria for volatile organic compounds (VOCs), which are constituents associated with petroleum products.

There are no underground or aboveground storage tanks containing POLs or hazardous materials and no oil/water separators on MMR. Tankers transport needed petroleum to the reservation and leave after fueling vehicles and equipment. Only necessary quantities of fuels and oils needed during training exercises are temporarily staged onsite (for example, gasoline needed for a generator would be stored in a canister next to the equipment). Unused fuels and oils are removed from the reservation by the unit.

3.7 Other Chemicals of potential concern

Many organochlorine pesticides degrade very slowly in the environment and may persist for many years after they are no longer in use. The USGS has found high levels of organochlorine pesticides in sediment and fish tissue in urban and mixed land use sites on Oahu (Brasher and Anthony 1999). USGS scientists note that aldrin, chlordane, and heptachlor were heavily used as termiticides in urban areas of Oahu until they were banned in the 1980s, and DDT was widely used until 1972. All of these pesticides have been detected at low concentrations in samples from MMR. Dieldrin was also detected in some samples; although it was not widely used in Hawai‘i, dieldrin’s presence may be attributable to the fact that aldrin rapidly degrades to dieldrin in the environment.

4.0 HYDROGEOLOGICAL HARACTERIZATION

Upon completion of well installations at Makua Military Reservation, measurements were collected to characterize the hydrogeologic conditions of the water bearing formations. These measurements established the configuration of the water table and its fluctuations, and provided approximations of hydraulic conductivity. Water levels were collected from the 10 monitoring wells prior to sampling the well. One complete set of water levels was collected at high tide and low tide in a period of less than one hour to allow for comparison between the wells. A transducer was placed in a well (SP-7) for several days to investigate the tidal influences on water levels. Results of the water level survey are outlined in Section 3.8 of this document.

Both falling head and rising head slug tests were conducted in each of the monitoring wells (SP-7 and ERDC-MW-1, 2, 3A, 3B, 4A, 4B, 5). These slug tests allowed for estimation of permeability in the formations in the Makua Valley. This involved the use of a solid slug that was placed in and out of the well, while the response of the well was measured with transducers and computer equipment.

4.1 Fate and transport modeling

Fate and transport analyses are conducted using the data collected as part of this study to estimate the potential for compounds introduced as part of military training to be transported offsite.

A site conceptual model was developed that explains processes in groundwater flowing through Makua Valley. Two primary pathways for both MMR and the OB/OD area are considered to be: (1) contaminant release into surface soils, percolation of contaminant from the surface into the groundwater and subsequent groundwater migration offsite to the ocean or near shore area; and (2) transport of soil particles containing contaminants that move with large rainfall events into streams discharging into the near shore area, Muliwai ponds, or ocean. To evaluate the potential travel times for compounds discharging to the ocean, both surface water and groundwater modeling were performed. In addition, other studies performed on –site and off-site that may provide estimates of impacts of off-site receptors are summarized.

4.2 Surface Water Modeling

The surface water modeling of the study was performed to provide estimates of groundwater recharge, and provide estimates of flow and sediment transport due to large rainfall events. The model also provides estimates of flooding inundation. The two-dimensional surface water model is designed to calculate the volume of flow at the outlet of the 3 streams in Makua: Punapohaku Steam, Koiahi Gulch Stream, and Makua Stream. The surface water modeling grid extends throughout Makua Valley from the top of the Waianae Mountains to the ocean.

The modeling was performed using the Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model (Downer and Ogden, 2002) along with the Watershed Modeling System (WMS) preprocessor and postprocessor. GSSHA is a physically based, distributed parameter model that simulates physical processes occurring in the watershed that produce stream flow and sediment movement. The model is able to explicitly account for the spatial distribution of land use, soil textures, vegetation and contaminant loadings in a much more rigorous way than lumped parameter models such as Hydrological Simulation Program Fortran (HSPF) (Donigian et al., 1984). The GSSHA model, developed with U.S. Army funds, was designed in part to assess the problem of soil erosion and contaminant flow due to overland flow from Department of Defense firing ranges. It has the capability to simulate multiple runoff mechanisms and is therefore applicable to a much wider range of problems than it’s

predecessor, CASC2D (Ogden and Julien, 2002, Downer et al., 2002). For this modeling effort, the model was designed to incorporate overland flow due to rainfall to stream channels, infiltration of rainfall into the land surface.

The GSSHA surface water model input data included parameters such as soil moisture content, vegetation type, soil type, and precipitation data. Soil moisture data was collected from soil samples taken throughout Makua Valley as part of this study. Soil moisture content and grain size analyses were collected and used as input for the model.

Precipitation data were collected from the existing MMR weather stations, and 8 rain gages placed throughout the Makua Valley. These 11 rainfall data points provided a detailed distribution of rainfall throughout the Valley during the simulated rainfall events.

Measurements or estimates of stream flow were made for Punapohaku Stream, Koiahi Gulch Stream, and Makua Stream. Distributed parameters in the model were based on land use and soil textural classification taken from a GIS database prepared by the Range Control Division of Schofield Barracks for Makua. Stream bottom shape and slope were collected at 10 locations throughout the valley to provide input into the computer model.

The preparation of the model involved incorporating digital topography (DEM, or digital elevation model) collected on a 5-meter grid throughout Makua Valley. This is extremely detailed topography, as most other sites simulated typically have only a 10 or 30-meter digital topographic map (DEM). The stream network was then added to the model. Punapohaku Stream, Koiahi Gulch Stream and Makua Stream were detailed and simulated as 1-D channels, with each stream having an outlet point for calculating the stream hydrograph.

The model grid was composed of 86 grid blocks in the east/west direction, and 57 grid blocks in the north-south direction with each square having a size of 75 meters. The model was run using a time step of 30 seconds. Infiltration was calculated using the Green and Ampt infiltration method. Due the short simulation period evapo-transpiration was negligible, and was not simulated. Initial moisture content of 20% was used for the model runs.

The streambeds were simulated as trapezoidal erodable channels. Soil erosion factors include crop management of 0.002 and conservation practices of 1.0. Both of these parameters are generally used for undeveloped land this is largely vegetated by grass or trees.

Additional model input parameters include the distributed overland flow roughness coefficient for the model area. This roughness value is analogous to a Manning's n value, and original values are estimated from standard literature sources that relate land use to overland flow roughness (Downer and Ogden, 2002).

Soil hydraulic properties that control infiltration values for different soil types throughout the Makua Valley are input parameters required for the model. Values for shallow vertical hydraulic conductivity (Ks) varied from 0.10 to 25 cm hr^{-1}. Most of the project area has the somewhat higher infiltration values of 25 cm hr^{-1}, with the streambeds and central areas having lower values of hydraulic conductivity. During simulations, the amount of infiltration is highly dependent on Ks, as well as the slope of the land surface (higher slopes have less infiltration and more runoff), capillary head (soil suction), and the soil porosity.

The parameters used in the model were calibrated using the February 14, 2003 flow event. The model incorporated overland flow, channel flow, and infiltration losses. The model was run for 1.7 days beginning at 0930 February 13, 2003, covering the period from the beginning of rainfall until the flow of water at the stream outlets had ceased. Output from the simulations included stream hydrographs, infiltration to groundwater, and suspended sediment transport. The surface water modeling effort is calibrated to the February 14, 2004 flow event. Since there are almost no detectable levels of potential contamination in the surface water, the output of the surface water modeling has been limited to evaluating flooding and sediment transport and not the impacts of chemical constituents to offsite receptors. Since limited evaluations are made with the model, the usefulness of the surface water modeling is diminished.

4.3 Groundwater Modeling

A three-dimensional flow and solute transport model was developed to provide an additional tool for evaluating the potential for transport of compounds related to military operation off-site. The model domain extends from the boundary of MMR at the top of the Waianae Range to the ocean. The models used were the U.S. Geological Survey's MODFLOW flow model (McDonald and Harbaugh, 1988) and the MT3D solute transport model (Zheng, 1990).

The U.S. Geological Survey's MODPATH (Pollack, 1994) model was also used to estimate groundwater flow paths and travel times within the Makua Valley. The model was created with the Department of Defense's Groundwater Modeling System (GMS) pre- and post-processing software. The MODFLOW model included transport within the saturated portions of the aquifer.

Transport of compounds potentially in the unsaturated zone was estimated using a FEMWATER (Ogden and Julien, 2002) finite element vadose zone model. The results were used as input into the saturated groundwater flow and solute transport models

The MODFLOW, MT3D, and FEMWATER model combination was used to estimate travel times for groundwater to flow from the recharge areas in the Waianae mountain range to the ocean. Travel paths of groundwater were from the training areas of concern (such as the OB/OD area) to potential offsite receptors are also estimated. Input from the entire sampling program, including the installation of monitoring wells, groundwater sampling, and slug testing.

4. SUMMARY AND CONCLUSIONS

MMR has been used for military training with live ammunition. A variety of ordnance and ammunition have been deposited throughout MMR. Possible compounds released by these munitions include metals, explosives, and byproducts of explosives. The objective of this project was to evaluate the extent of explosives contamination at the site and to confirm that natural attenuation of explosives occurs through a comprehensive monitoring program. Previously, under a comprehensive research project, natural attenuation of explosives at other sites was demonstrated.

The surface water models showed that a high percentage (greater than 80%) of both measured and estimated rainfall in Makua Valley infiltrates to the soil, with a smaller percentage (less than 20%) flowing off the site in the stream flow. The model also showed that the total of suspended sediment discharge in the streams is small. Also, a large portion of the bottom of Makua Valley would be flooded by a large rainfall event, such as the 100 year, 24 hour storm.

The groundwater modeling was performed to estimate the fate and transport of RDX in the impact area and the OB/OD area. Groundwater samples collected in the 10 monitoring wells showed that groundwater chemistry has not yet been impacted by RDX. The modeling was conducted to evaluate what concentrations might be should RDX flow off-site in groundwater flow. Groundwater flow is slow in Makua Valley; hence, the natural processes may degrade or dilute the compounds long before measurable concentrations might reach the coast. However, the results showed that the 10 monitoring wells in the Makua Valley would be impacted before explosive compounds such as RDX impact off-site receptors. The study concluded that the basal aquifer at MMR was not contaminated.

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